Focused Ultrasound Techniques for the Small Animal Practitioner
Focused Ultrasound Techniques for the Small Animal Practitioner

Edited by

Gregory R. Lisciandro

WILEY Blackwell
DEDICATION

To my grandparents Sam and Bernice Long and John and Mary Lisciandro; my parents Richard and Judy and siblings Denise, Kim, Kelly, and John; and most especially my lovely wife Stephanie and our children Noah, Hannah, Sarah, and Joshua for their patience, encouragement, and inspiration; and lastly the good Lord for making the textbook and all its many variables miraculously fall in place to its completion.
## CONTENTS

Contributors ix

Acknowledgements x

Introduction xi
Gregory R. Lisciandro

About the Companion Website xiv

1 Focused—Basic Ultrasound Principles and Artifacts 1
   Robert M. Fulton

2 The Abdominal FAST$^3$ (AFAST$^3$) Exam 17
   Gregory R. Lisciandro

3 Focused or COAST$^3$—Liver and Gallbladder 44
   Stephanie Lisciandro

4 Focused or COAST$^3$—Spleen 65
   Stephanie Lisciandro

5 Focused or COAST$^3$—Kidneys 80
   Stephanie Lisciandro

6 Focused or COAST$^3$—Urinary Bladder 99
   Stephanie Lisciandro

7 Focused or COAST$^3$—Gastrointestinal and Pancreas 110
   Søren Boysen and Jennifer Gambino

8 Focused or COAST$^3$—Reproductive 126
   Robert M. Fulton

9 The Thoracic FAST$^3$ (TFAST$^3$) Exam 140
   Gregory R. Lisciandro
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>The Vet BLUE Lung Scan</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>Gregory R. Lisciandro</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Focused or COAST³—ECHO (Heart)</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>Teresa DeFrancesco</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Focused or COAST³—Central Venous and Arterial Line Placement,</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td>Big Arteries, and Veins</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scott Chamberlin</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Focused or COAST³—Pediatrics</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>Autumn P. Davidson and Tomas W. Baker</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Focused or COAST³—Eye</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>Jane Cho</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Focused or COAST³—Musculoskeletal</td>
<td>261</td>
</tr>
<tr>
<td></td>
<td>Gregory R. Lisciandro</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Focused or COAST³—Cardiopulmonary Resuscitation (CPR), Global FAST</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>(GFAST³), and the FAST-ABCDE Exam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gregory R. Lisciandro and Andrea Armenise</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Interventional Ultrasound-Guided Procedures</td>
<td>286</td>
</tr>
<tr>
<td></td>
<td>Søren Boysen</td>
<td></td>
</tr>
</tbody>
</table>

**Appendices** 304

I Setting Up an Ultrasound Program 304

II Goal-Directed Templates for Medical Records 306

III Abbreviations, Terminology, and Glossary 315

IV Quick References of Normal Values and Rules of Thumb 318

V Ultrasound Resources and Companies 324

Index 325
Contributors

Andrea Armenise, DVM
WINFOCUS Veterinary Care Section Coordinator
www.winfocus.org
Ospedale Veterinario Santa Fara
Bari, Italy

Tomas W. Baker, MS
Department of Surgery and Radiological Sciences
School of Veterinary Medicine
University of California
Davis, California

Søren Boysen, DVM, Dipl. ACVECC
Associate Professor, Faculty of Veterinary Medicine
Department of Veterinary Clinical and Diagnostic Sciences
University of Calgary
Calgary, Canada

Scott Chamberlin, DVM
Resident, Emergency and Critical Care
College of Veterinary Medicine and Biomedical Sciences
Colorado State University
Fort Collins, Colorado

Jane Cho, DVM, Dipl. ACVO
Veterinary Eye Specialists, PLLC
Ardsley, New York

Autumn P. Davidson DVM, MS, Dipl. ACVIM
Department of Medicine and Epidemiology
School of Veterinary Medicine
University of California
Davis, California

Teresa DeFrancesco, DVM, Dipl. ACVECC, Dipl. ACVIM (Cardiology)
Professor, College of Veterinary Medicine
North Carolina State University
Raleigh, North Carolina

Robert M. Fulton, DVM
Resident, Theriogenology
Betty Baugh’s Animal Clinic
Richmond, Virginia

Jennifer Gambino, DVM
Clinical Instructor
Department of Diagnostic Imaging, Animal Health Center
Mississippi State University College of Veterinary Medicine
Starkville, Mississippi

Gregory R. Lisciandro, DVM, Dipl. ABVP, Dipl. ACVECC
Consultant, Hill Country Veterinary Specialists
Chief of Emergency Medicine and Critical Care, Emergency Pet Center, Inc.
San Antonio, Texas
Woodydvm91@yahoo.com
www.fastvet.com

Stephanie Lisciandro, DVM, Dipl. ACVIM
Consultant, Hill Country Veterinary Specialists
Staff Internist, Mission Veterinary Specialists
San Antonio, Texas

Sarah Young, DVM
Mobile Ultrasonographer
Echo Service for Pets
Ojai, California
Acknowledgements

Words cannot express my eternal gratitude to Drs. Mike Lagutchik, Kelly Mann, Geoffrey Fosgate, and Andra Voges for their efforts; doctors; technicians; Mr. Adrian Ford and Dr. Tom Hanna of the Emergency Pet Center, Inc., for enthusiastically helping complete novel clinical research in a private practice setting; and Robert Whitaker, who believed in the abbreviated ultrasound format and gave me a beginning in training veterinarians in these focused assessment with sonography for trauma (FAST) techniques.

The following individuals made significant contributions to the textbook: Nancy Place, MS, Association of Medical Illustrators, who provided much of the illustrative artwork in the Abdominal FAST, Thoracic FAST, and Vet BLUE chapters; Alice MacGregor Harvey, medical illustrator, North Carolina State College of Veterinary Medicine, who provided the illustrative artwork in Chapter 11; Dr. Maria Hey, who formatted and arranged all of the book’s images; Dr. Jennifer Gambino, who additionally helped with editing chapters 3 and 5; Dr. Sarah Young, who provided many of the excellent ultrasound images and reviewed portions of the manuscript; Guy Hammond of Veterinary Imaging, for ultrasound machine/equipment support and his leadership in creating the General Practice Ultrasound Group (GPUS) made up of Drs. John Mattoon, Marti Moon, Sarah Young, Ron Kelpe and myself; Dr. Warren “Sherm” Mathey who read nearly the entire manuscript; Dr. Søren Boysen, for his tireless support, encouragement, and constructive criticism from the very beginning of our FAST start in 2005; Erica Judisch, Susan Engelken, and the entire Wiley Blackwell team for their patience and support; and Dr. Stephanie Lisciandro for her additional time and efforts in the editing process.

Finally, thank you to each of the chapter authors, Andrea Armenise, Tomas Baker, Søren Boysen, Jane Cho, Scott Chamberlin, Autumn Davidson, Teresa DeFrancesco, Robert Fulton, Jennifer Gambino, and Stephanie Lisciandro, who not only believe in the potential for abbreviated ultrasound exams to make a significant positive impact on veterinary medicine, but who also generously gave their time and expertise in making this project possible. To them, I am forever grateful.
**Introduction to Focused Ultrasound for the Small Animal Practitioner**

Gregory R. Lisciandro

The translational study from the human to the veterinary patient regarding the focused assessment with sonography for trauma (FAST) exam by Dr. Søren Boysen in 2004 has opened the veterinary imaging world’s eyes to legitimate non-radiologist use of abbreviated ultrasound exams. Such exams are of utmost importance because they are safe (no radiation) and non-invasive, allowing point-of-care evaluation of short-duration with limited patient restraint. These ultrasound interrogations also carry the potential to answer clinically important questions that remain enigmatic by using traditional means of physical examination, laboratory findings, and radiographic imaging. Moreover, by using abbreviated ultrasound exams, patients have the potential to survive because traditionally occult life-threatening disease was historically missed without using ultrasound. By using abbreviated ultrasound exams, disease may be detected on our terms rather than the disease’s in the midst of traditionally less sensitive means, and the delay of scheduling formal or complete ultrasound exams or other advanced imaging studies is avoided. In human medicine, the so-called turf wars between who should and should not be conducting ultrasound studies has been somewhat mitigated by the realistic impression that abbreviated exams not only detect disease in a more timely manner, but also keep patients alive by better directing care. As more patients survive, the need for formal or complete ultrasound studies or other advanced imaging techniques increases. In other words, the human and veterinary radiologist to the contrary may become even busier.

The readers of this text should review the following sections to optimize the didactic potential of our textbook. We welcome feedback (woodydvm91@yahoo.com; www.fastvet.com) from your experiences as general practitioners and emergency and critical care veterinarians on the front lines of veterinary medicine.

**Terminology**

For a grasp of some of the concepts described below and throughout the subsequent chapters, let’s define a few things.

**The Abbreviated Ultrasound Exam**

With the sudden eruption of bedside ultrasound exams by non-radiologists in human medicine, terminology has become convoluted, but generally the term “bedside” seems to be winning out. For example, a bedside gallbladder exam will be called just that, with its objectives being to answer simple clinical questions to help expediently guide the clinical course and to trigger the possible need for more formal (or complete) ultrasound examinations or other advanced imaging. On the other hand, the veterinary bedside lung ultrasound exam (called Vet BLUE) is similarly performed, however, it has been given an acronym. For clarity and to prevent an onslaught of terminology in veterinary medicine, we will use a limited number of terms.

Abbreviated ultrasound exams may be termed either “focused X” or “focused Y” exams, as suggested by the General Practitioner’s Ultrasound Group (GPUS Group, www.gpultrasound.org) (see Appendix V for Internet access to the document). Such exams also may be referred to analogously as in the human literature, replacing “bedside” with “cageside.” Thus, a “cageside organ assessments for trauma, triage, and tracking” may be turned into the acronym “COAST3” and similarly used as a “COAST3 X” or “COAST3 Y” exam with the “T3” standing for trauma, triage, and tracking (monitoring) subsets of veterinary patients. The “T3” has been previously proposed in the veterinary literature regarding the use abdominal FAST (AFAST) and thoracic FAST (TFAST) exams (Lisciandro 2011). Thus, the terms AFAST3 and TFAST3 seem best suited for use in many non-trauma subsets of veterinary patients for triage and tracking.
Importantly, the standardization of veterinary terminology gives absolute clarity among colleagues as to the exact exam format being performed. The accepted use of these veterinary terms has been previously proposed for preventing an onslaught of terms in veterinary medicine (avoiding what has occurred in human medicine) (Lisciandro 2011).

The terminology for radiologist-performed exams in human medicine has generally taken on the term “formal” abdominal ultrasound or “formal” echocardiography. The use of “diagnostic” is not adequate and should be discouraged in veterinary medicine because any abbreviated ultrasound exam format may be “diagnostic.” Rather than use the term “formal,” consistent with human terminology, we use the term “complete,” as suggested by the GPUS Group. Thus, the terminology for veterinarians is as follows for the abdominal cavity and thorax, respectively: “complete abdominal ultrasound” and “complete echocardiography.”

Recording Findings of the Focused, COAST³ and FAST³ Exams

The authors of this textbook acknowledge that each of these abbreviated ultrasound exams will evolve over time as to the diagnostic abilities in terms of their sensitivity, specificity, and accuracy. At this time, the best way to study results seems to be through template, goal-driven, formatted entries for medical records. In a bold attempt, by using both our experiences and those of the GPUS Group, such examples have been listed in the Appendices (Appendix II) and should be reviewed (and we encourage their use) by our readers.

Echogenicity: The Whites, Grays, and Blacks of Ultrasound

The jargon of ultrasound can be intimidating to the novice non-radiologist ultrasonographer. Clarity may be accomplished through acknowledging that ultrasound is the opposite of what tissues appear as on radiographic studies (our brain needs to reformat itself). For example, and very simplistically, air is white on ultrasound and black on radiographs. Bone is black (shadows) on ultrasound and white on radiographs. The ultrasound terms describing whites, grays, and blacks are referred to as hyperechoic, hypoechoic, and anechoic, with the terms “relative to X” and “relative to Y” used to further describe ultrasound imaging when detail is somewhere in between (Figure 1). For example, the spleen is hyperechoic (brighter) when compared to the left kidney. A few definitions:

Anechoic (pure black): Occurs when no ultrasound waves are reflected back to the receiver. Thus, normal urine, normal bile, transudates, and blood all are purely anechoic (black).

Hypoechoic (shades of gray): Occurs when variable degrees of the ultrasound waves are reflected back to the receiver. Thus, all soft tissues that are not fully aerated are described relative to other distinct tissues; for example, the liver is hypoechoic (darker than) relative to the spleen.

Hyperechoic (whites, bright whites): Occurs when all or nearly 100% of ultrasound waves are reflected back to the receiver. Thus, bone, stone (metals), and air are strong reflectors, resulting in hyperechoic interfaces with either shadowing, comet-tail artifacts, ultrasound lung rockets, or reverberation artifact projected distally.

Isoechoic (same echogenicity): Occurs when tissues are the same shades of gray. For example, if the liver is isoechoic to the spleen, then they are the same echogenicity (same shades of gray).

Directional Terms for Orientation

Longitudinal and sagittal: The term longitudinal refers to orientation parallel to the spine or long-axis of the patient’s body. The term sagittal refers to the longitudinal axis of the respective deeper structure being evaluated. For example, the superficial jugular vein is imaged in longitudinal, whereas the deeply located right kidney (angled and not parallel to the body’s long-axis) is imaged in sagittal planes (parallel to the right kidney’s long-axis). The terms are often
used interchangeably (or arguably misused); however, by appreciating that both terms are in their own right long-axis views, directional communication between veterinarians seems to be clear by use of either term. The probe marker is directed toward the patient’s head.

Transverse: The term transverse refers to orientation 90 degrees to the long-axis of the structure being evaluated. The probe marker is turned to the left (or counterclockwise) to the patient’s right side (if in dorsal recumbency or right lateral recumbency).

With that said, let’s get on with Chapter 1. And remember, focused and FAST® saves lives.

Reference

This book is accompanied by a companion website:

www.wiley.com/go/lisciandro/ultrasound

The website includes a video bank containing more than 80 videos.
CHAPTER ONE

FOCUSED—BASIC ULTRASOUND PRINCIPLES AND ARTIFACTS

Robert M. Fulton

Introduction

Turn on the machine. Apply coupling gel. Start scanning. In the realm of the busy veterinary general practice, emergency clinic, or intensive care unit, that statement really sums up the basic use of ultrasound. Just as natural as it is for us to take the stethoscope from around our neck and place it on a patient’s thorax, so should be picking up the ultrasound probe and placing it on the patient. No wonder that ultrasonography has been appropriately dubbed both “an extension of the physical exam” and the “modern stethoscope” (Rozycki 2001; Filly 1988). Really, one doesn’t need a whole lot of instruction to start scanning; however, as for a lot of things in life, the devil is in the details. Proper imaging technique and understanding its limitations are the keys to accurate image interpretation of diagnostic ultrasound.

The focus of this chapter is a fairly brief review of the basic physics and principles of ultrasound including the more common problematic artifacts. For interested readers, there are more comprehensive textbooks dedicated to the physics and interpretation of ultrasound imaging (Nyland 2002; Penninck 2002).

What Focused Basic Ultrasound Principles and Artifacts Can Do

• Provide a basic review of ultrasound physics, image formation, common artifacts, and ultrasound systematics
• Provide a basic understanding of how artifacts are formed to allow better interpretation of the ultrasound image

What Focused Basic Ultrasound Principles and Artifacts Cannot Do

• Cannot provide an in-depth discussion of ultrasound physics, principles, and artifacts

Indications

• Provide a basic understanding of ultrasound physics, principles, and artifacts for the non-radiologist veterinarian

Objectives

• Provide an understanding of the basic fundamentals of ultrasound physics and how they relate to image formation
• Provide an understanding of how basic ultrasound artifacts are formed to avoid misinterpretation
• Provide a review of basic ultrasound systematics including image orientation and storage and machine and probe care

Basic Ultrasound Principles

The ultrasound (US) machine consists of two main parts, the probe and the processor. The probe is the “brawn” and the processor the “brains” of the operation. The probe has two main functions: first, to generate a sound wave (acts as a transmitter); second, to receive a reflected sound wave (acts as a receiver). The processor, located within the mainframe, takes these incoming signals and turns them into a useful image.
The transmitter and receiver functions of the transducer do not occur simultaneously, but rather sequentially. When placed under mechanical stress the ceramic crystals in the transducer generate a voltage. This process, known as the piezoelectric effect, occurs during the receiving phase, which is when returning sound waves strike the transducer. When an external voltage is applied to the crystals they exhibit the reverse phenomenon and undergo a small mechanical deformation. The subsequent release of this energy generates the ultrasound wave. This is known as the reverse piezoelectric effect. World War I saw the first practical use of the piezoelectric effect in the development of sonar using a separate sound generator and detectors (Coltera 2010).

The sound waves generated by diagnostic US machines are typically in the 3- to 14-megahertz (MHz) range and are thus too high pitched to be perceived by the human ear. We can hear sounds in the range of 20 Hz (cycles/second) to 20,000 Hz. In contrast, our average canine patient hears sounds in the range of 40 Hz–60,000 Hz. The high frequencies are in the realm of what is termed the “ultrasonic” range—basically any sound above our ability to hear—and hence the name for this clinical tool (Nyland 2002).

The sound waves produced by the transducer penetrate the body tissues and are subject to all the rules surrounding any sound wave including reflection, refraction, reverberation, attenuation, and impedance. The processor analyzes the transmitted signals and the returning waves, including their quantity, strength, and the time they took to return. By applying pre-programmed algorithms, the processor translates this information into a pixel, gives it an appropriate intensity (its echogenicity), and places it on the monitor screen to give us the image (sometimes being “fooled” into creating artifacts).

Between the transducer and the processor, it is easy to see why the equipment for this modality can be rather pricey. However, by using the variety of focused or COAST ultrasound exams outlined in this textbook, we hope that your US machine will become an asset not only with improved patient care, but also with a return on investment.

**Velocity**

Sound travels at specific known velocities through various materials. Remember from physics that sound travels faster though solids than it does through liquid or gas, and its velocity through various body tissues is known (Figure 1.1). Notice that velocity is similar through most of the soft tissues; however, current US machines cannot determine what tissues are being penetrated. Therefore, all US machines use an average velocity of 1540 m/sec for their imaging algorithms averaging the speed of sound through fat, liver, kidney, blood, and muscle (Coltera 2010).

The first and last columns in the table illustrate that sound passes relatively slowly through air and relatively quickly through bone. Anyone who has picked up an US probe knows that bone (solid) or lung (air) cannot be adequately imaged using US. To address the issue, the sonographer must understand the principle of acoustic impedance.

**Acoustic Impedance**

Acoustic impedance refers to the reflection and transmission characteristics of a substance. It is a measure of absorption of sound and the ratio of sound pressure at a boundary surface to the sound flux. Sound flux is

![Figure 1.1. Velocity (m/sec) of sound through common body tissues or substances. Note the similar velocity through most soft tissues. This is the basis for using 1,540 m/sec as the number in depth calculations by the ultrasound processor. (Coltrera 2010)
flow velocity multiplied by area. If we draw an analogy to electronic circuits, acoustic impedance is like electrical resistance through a wire, sound pressure is like voltage, and flow velocity is like current. The equation that brings it all together is:

\[ Z = \frac{p}{v} \]

where \( Z \) = acoustic impedance, \( p \) = sound pressure (or tissue density), and \( v \) = velocity (Nyland 2002). The amplitude of a reflected sound wave is proportional to the difference in acoustic impedance between two different tissues. Air has a low impedance and bone has a high impedance when compared to soft tissue (Reef 1998) (Figure 1.2). Therefore, when a sound wave comes across a soft tissue-bone or a soft tissue-air interface (large difference in acoustic impedance), nearly all of the sound waves are strongly reflected (and a bright white echogenic line is formed at either interface). Reflection is why the sonographer cannot image through bone (solid) or lung (air), and strikes up one of the most common misnomers used in clinical ultrasound: When imaging through the liver into the thorax, we believe the bright, curved cranial border is the diaphragm. In reality, the diaphragm is rarely imaged except in bicavitary effusions. The bright white (hyperechoic), curved line is actually the strongly reflective surface of the lung (air) at the soft tissue-air boundary or interface serving as a strong reflector.

In conclusion, by comparing the acoustic impedance of most tissues in the body—other than bone (solid) and lung (air)—we see that they are very similar (there is little difference in acoustic impedance among them). This similarity makes US a great imaging tool for examining into and through soft tissues (their parenchyma). On the other hand, due to the large difference in acoustic impedance between soft tissue-air and soft tissue-bone interfaces, US is not an effective tool for examination beyond the surfaces of either aerated lung or bone (Reef 1998).

**Absorption, Scatter, and Reflection**

Other US principles that affect our image include absorption, scatter, and angle of reflection. As the sound waves enter the body, some of them are absorbed by the tissues and are never reflected back to the probe. These waves are lost and do not contribute to the image. Furthermore, many of the waves are scattered by the tissues and their surface irregularities and either return to the probe (receiver) in a distorted path or do not return at all. As a result, the US waves are “misinterpreted” by the processor and the image and its resolution are affected. The ideal angle of US reflection for generating the best image is 90 degrees; this is why linear probes (not used by most small animal practitioners) provide superior detail when compared to curvilinear probes (more commonly used among small animal practitioners). Interestingly, a deviation of as little as 3 degrees from this ideal causes US waves to be lost and not returned to the receiver, thus decreasing the detail of the US image.

**Attenuation**

All sound beams become attenuated, or lose energy, during transmission through tissues; therefore, the returning sound wave is weaker than when it started. Different frequencies (MHz) are attenuated to different degrees. Low frequency is attenuated less than high frequencies and therefore allows deeper tissue penetration. Conversely, high frequency gives better resolution but undergoes more attenuation. Strategies that include lowering the MHz for better penetration (depth) come at the expense of detail. Conversely, using higher frequency for more detail comes at the

**Figure 1.2.** Acoustic impedance \((10^6\text{kg/m}^2\text{sec})\) of common body tissues or substances. This figure illustrates the degree of difference in acoustic impedance between substances that helps determine sound wave transmission. The greater the difference, the greater reflection or loss of transmission. You can see how ultrasound is ideally suited for most soft tissue and why it is not suited for imaging bone or air-filled structures. (Reef 1998)
cost of less penetration (depth). Furthermore, high-density tissues attenuate the sound waves more than low-density tissues (Figure 1.3). These principles will be further discussed in Basic Artifacts.

The analogy of hearing a boom box from a distance can help you remember which MHz penetrates more. The bass dominates (low MHz) over higher frequencies (high MHz); thus, low MHz penetrates deeply at the expense of detail, and high MHz gives better detail at the expense of penetration.

Basic Artifacts

Now we’ll take the fundamental laws governing wave dynamics and see how artifacts are created. Artifacts may be grouped by the most important principles leading to their formation including attenuation, velocity, or propagation, and artifacts associated with multiple echoes.

**Artifacts of Attenuation, Strong Reflectors (Bone, Stone, Air)**

**Shadowing, “Clean” and “Dirty”**

Clean shadows and dirty shadows result from strong reflectors (bone, stone, and air). We know from differences in acoustic impedance at soft tissue-air and soft tissue-bone (stone) interfaces that most of the sound waves will be reflected, albeit in different degrees (Figures 1.4 and 1.5A).

**Bone (or Stone) Interface**

When the US wave strikes bone (and stone), most of the waves are reflected back thus there will be an area of intense hyperechogenicity (whiteness) at the soft tissue-bone (stone) interface. Because the surface of bone is often smooth, there is little scattering or reverberation of the US wave and a nice, clear-cut, anechoic (blackness) “clean shadow” is produced beyond the reflector (bone or stone) (Figure 1.4B, also see Figures 15.1, 15.2, 15.6, and 15.7).

**Air Interface**

On the other hand, soft tissue-air interfaces are more variable in their degree of reflection with some of the US waves incompletely moving through the air-filled structure unlike the complete reflection at bone (or stone); thus reverberations occur distal to the air interface creating a “dirty shadow.” (Penninck 2002) (Figure 1.4A, 1.5A).

**Artifacts of Attenuation (Fluid-Filled Structures)**

**Edge Shadowing (Fluid-Filled Structures)**

When the US waves strike the edge of a fluid-filled structure with a curved surface (its wall), such as the stomach wall, urinary bladder, gallbladder, or cyst, US waves change velocity and bend, resulting in the physical process of refraction. As a result, a thin hyperechoic (darker) to anechoic (black) area lateral and distal to the edge of the curved structure is formed. The novice may mistake this artifact as a “rent” in the urinary bladder wall when in fact it is an artifact created by the US machine (Nyland 2002) (Figure 1.5).

**Acoustic Enhancement (Fluid-Filled Structures)**

When the sound beam passes through a fluid-filled structure, such as the gallbladder, urinary bladder, fluid-filled stomach, or a cyst, US waves do not become...
as attenuated as the neighboring waves passing through more solid tissues to either side of the structure. Therefore, the tissues on the far side of the fluid-filled structure appear much brighter than the neighboring tissues at the same depth. Acoustic enhancement is obvious, looking past the fluid-filled gallbladder and urinary bladder (Figure 1.6). On the other hand, by realizing how the artifact is formed, the acoustic enhancement artifact can be advantageously useful to the savvy sonographer in determining if a structure of interest is

Figure 1.4. Clean versus dirty shadowing. (A) “Dirty” shadow. A gas bubble within a fluid-filled distended loop of small bowel generates a dirty gas shadow (image on the left) because some US waves pass through the structure. Contrast the dirty shadow with the “clean” shadow of the cystourolith (urinary bladder stone) in (B). Note how a body icon was used to show the approximate location of the probe because there are no anatomical landmarks within the image itself. (B) “Clean” shadow. The smooth surface of the cystourolith (urinary bladder stone) generates the clean shadow typical of bone or stone with a hyperechoic (bright white) reflective surface in the near field, completely blocking all echoes and thus resulting in an anechoic (dark or black) shadow extending from it. Courtesy of Dr. Sarah Young, Echo Service for Pets, Ojai, California.

Figure 1.5. Edge shadow artifact. (A) An edge shadow artifact is seen arising from the curved edge on the left side of the stomach wall in this image, making its wall appear to extend distally as an anechoic (dark or black) line. A dirty gas shadow is also produced from gas within the stomach lumen. (B) An edge shadow artifact at the apex of the urinary bladder makes it falsely appear to have a rent which can fool the novice into thinking the free fluid is from a ruptured bladder. Courtesy of Dr. Sarah Young, Echo Service for Pets, Ojai, California.
Fluid-filled (brighter through the far field having acoustic enhancement) or soft tissue (lacking acoustic enhancement) (Penninck 2002) (Figure 1.6).

**Artifacts of Velocity or Propagation**

**Mirror Artifacts (Strong Reflector [Air])**

When we image a structure that is close to a curved, strong reflector such as the diaphragm (actually the lung-air interface following the curve of the diaphragm), a sound beam can reflect off the curved surface, strike adjacent tissues, reflect back to the curved surface, and then reflect back to the transducer. Because the processor only uses the time it takes for the beam to return home and cannot “see” the ongoing reflections, it will be fooled into placing (mirroring) the image on the far side of the curved surface. The classic place for a mirror artifact is at the diaphragm, and the classic mistake is interpreting the artifact as a diaphragmatic hernia (Penninck 2002) (Figure 1.7).

**Reverberation or A-Lines (Strong Reflector [Air])**

Reverberation occurs when sound encounters two highly reflective layers. The sound is bounced back and forth between the two layers before traveling back. The probe will detect a prolonged traveling time and assume a longer traveling distance and display additional reverberated images in a deeper tissue layer. The reverberations can get caught in an endless loop and extend all the way to the bottom of the screen as parallel equidistant lines, referred to as A-lines (also see chapters 9 and 10). This artifact most commonly extends beyond air-filled structures within the thorax, (e.g., lung) and within the abdomen (e.g., gastrointestinal tract), with varying width (Penninck 2002) (Figures 1.8A, Figure 1.5A).

**Comet-Tail or Ring-Down Artifact (Strong Reflector [Usually Metal or Bone but Can Be Air])**

A comet-tail artifact, also called a ring-down artifact, is similar to reverberation. It is produced by the front and back of very strong reflectors with high acoustic impedance, such as metallic foreign bodies or implants, needles, and stylets during US-guided procedures (chapters 12 and 17), or strong reflectors with very low acoustic impedance, relative to their adjacent soft tissues, such as gas in the lung, gas bubbles, or gas in the bowel. The reverberations are spaced very narrowly and blend into a small band. The greater the difference between the acoustic impedance of the reflecting structure and the surrounding tissues, the greater the number of reverberation echoes (Reef 1998) (Figure 1.8B).

**Ultrasound Lung Rockets or B-Lines (Air Immediately Next to Water)**

Ultrasound lung rockets (ULRs), more recently termed B-lines (Volpicelli 2012), are vertical, narrow-based lines arising from the near field’s pulmonary-pleural line, extending to the far edge of the ultrasound screen, always obliterating A-lines, and moving “to and fro” in concert with inspiration and expiration. Although ULRs
are similar to comet-tail artifacts, they are specifically created by the strong impedance of air adjacent to a small amount of water, and are the ultrasound near equivalent of radiographic Kerley B lines (representing interlobar edema). Their clinical relevance is very important and explained later (chapters 9 and 10) (Lichtenstein 2008, 2009, Lisciandro 2011, Volpicelli 2012) (Figure 1.9).

**Artifacts of Multiple Echoes**

**Side-Lobe Artifact**

We like to think of the ultrasound beam as extending from the probe in a very thin fan or rectangle, and this is exactly what the processor thinks it sees. In reality, there are smaller beams that travel laterally to the main beam. When one of these smaller side beams is of sufficient strength and bounces off a highly reflective surface, such as the wall of the urinary bladder, it will be interpreted as coming from the main beam and the processor will place the resulting image within the bladder, mimicking sediment. The resulting image is usually weaker in intensity than the main image. It is possible that the artifact can be altered by changing probes or dropping the focal point, or that it will disappear with lower gain settings—all things that will not happen with true pathology (i.e., bladder sediment, bladder stones, etc.) (Penninck 2002) (Figure 1.10).

**Slice-Thickness Artifact**

Slice-thickness artifact is somewhat similar to the side-lobe artifact. Particularly in the gallbladder and urinary bladder, this artifact mimics sludge or sediment. It occurs when part of the beam’s thickness lies just outside of a fluid-filled structure. These artifacts...
typically appear within the lumen of these structures and are somewhat hyperechoic (bright) and curved. They can be differentiated from real sediment by several methods or clues. First, gravity dependent sediments have a flat surface, whereas the artifact will be rounded. Second, by changing the position of the patient, the relative position of true sediment will change as gravity pulls it to the new lower point. Third, the sonographer can use the US probe to ballot the bladder and stir the sediment up a bit; the artifact will not yield a “snow globe” effect (sediment will) (Penninck 2002) (Figure 1.10).
As veterinarians, we are taught how to communicate with each other in such a way that regardless of our individual personality and training, one veterinarian can describe a lesion to another half a world away and pass along vital information. Ultrasound exams likewise need to have standard image orientation and recording of findings to give the study meaning.

For standard plain radiography, the lateral film is oriented with the patient’s head to the left, and the spine is dorsum and at the top of the viewer. This is the same for either a right or left lateral image. For the...
ventrodorsal or the dorsoventral view, the radiograph is positioned with the head pointed up, and the patient’s right side toward the left-hand side of the view box.

Ultrasound follows similar convention. When we scan from the ventral aspect (as when the patient is in dorsal recumbency), the following orientations apply:

**Longitudinal image:** The ventrum is on the top of the screen, dorsum on the bottom. Cranial is to the left, and caudal is to the right (Figure 1.11A).

**Transverse image:** Ventral and dorsal remain top and bottom, respectively, and the patient’s right side is represented on the left side of the screen, and the patient’s left side is represented on the right side of the screen (Figure 1.11B).

---

**Figure 1.11.** Standard ultrasound screen orientation, longitudinal (sagittal) and transverse. The radiograph for each orientation is located below the respective ultrasound image. Figures (A) and (C) illustrate longitudinal (or sagittal) and (B) and (D) transverse orientation with the corresponding probe position during interrogation of the liver and gallbladder via the subxiphoid region of a dog. Note that the reference icon (GE_{le}) corresponds with the probe reference marker (dot on the probe) with the GE_{le} reference icon (labeled with arrow in (A) to the left on the US image). The best way to make standard ultrasound imaging a habit is to have the probe marker toward the head for longitudinal (or sagittal) orientation (black dot on the probe in (C) and turn (the probe head) left or counterclockwise for transverse orientation (black dot on the probe in (D) with the reference icon (in this case the GE_{le}) to the screen’s left (shown at the top of the US image in (A) and (B)). If your reference icon is to the right of the US image, most US machines have a “reverse” button feature on their keyboard to flip the reference icon back to the standard left side (with the exception of echocardiography orientation; see Chapter 11).
This US image orientation convention is the most intuitive if the patient is positioned in dorsal recumbency with its head facing the same way the sonographer is facing (toward the machine). Many emergent patients are not stable enough to be placed in dorsal recumbency and all FAST scans actually prescribe lateral or sternal recumbency, so the sonographer may need to do a little mental gymnastics at times to orient the image on the screen with the patient.

When scanning from the lateral aspect of the patient (i.e., in a dorsal plane), the following convention applies:

Longitudinal image: Non-recumbent side is on top of the screen, recumbent side is on the bottom. Cranial is to the left side of the screen, and caudal is to the right (Figure 1.11A).

Transverse image: Non-recumbent side is still on top of the screen, recumbent side still on screen’s bottom. Ventral is on the left, dorsal is on the right (Figure 1.11B).

All US probes have a reference mark to allow for proper orientation. The marker may be a raised dot or line molded into the plastic, or possibly a small LED light. On the image screen, there will be a symbol (often the company’s logo) that corresponds with the probe’s reference mark. The marker on the screen is commonly referred to as the “reference icon” (Figure 1.11). Sonographers should familiarize themselves with the various types of US probes—phase array, linear, and curvilinear—and know that by looking at the shape of the US image the probe is readily apparent—pie-shaped pointed near field (phase array or sector), rectangular (linear), and pie-shaped with curved concave near field (curvilinear) (Figure 1.12).

Most veterinarians are taught that when scanning the abdomen in long-axis, the probe’s reference mark is pointed toward the patient’s head. Therefore, by convention, the reference icon on the screen will also be positioned on the left side of the screen (left=cranial, right=caudal). When the probe is turned into the transverse orientation, the reference mark is pointed toward the patient’s right, making a counterclockwise motion (“turning left”) if one views the probe from its tail, or cable, end (left=right side of patient, right=left side of patient).

**Cardiac Orientation**

See chapters 9 (TFAST) and 11 (focused ECHO) for information on cardiac orientation.

**Deciding on an Ultrasound Machine**

**Selecting the Machine**

There are three main types of US machines: consoles, portables, and handhelds. The console machines are big and bulky, but they have stronger processors and thus give a better image. The portables, often laptop format, are easy to move to the exam table or cageside and their image quality is constantly improving. There a several small handheld machines now on the market. Some have pretty decent depth and resolution capabilities. Just make sure they don’t walk out of your clinic. It’s very easy to put these in a lab jacket pocket and forget about them.

You may be limited to whatever you currently have in your veterinary practice, but if you are thinking of buying a new unit, consider what your main use is going to be, and get the best US machine you can afford for that purpose. The axiom holds true—the better the machine, the better the image, and the better the diagnostic information.

**Selecting the Probe**

Probes, or transducers, come in two basic types, mechanical and electronic. Mechanical probes are by many accounts considered outdated but there are still some around with their working parts visibly rotating or rocking under their translucent covers. Newer ultrasounds come standard with electronic probes. Electronic probes come in various arrangements. Probes are generally described by the size and shape of their face, referred to as their “footprint,” which is represented by the gray rubber probe covering (Figure 1.12A). Selecting the right probe is essential to getting good images, although there may be times when more than one probe may be appropriate for a given exam.
Three basic types of probes are used in general practice, emergency, and critical care point-of-care ultrasound: linear, curvilinear, and phased-array (also known as sector) (Figure 1.12A). Linear probes are typically of higher frequency and have a rectangular footprint (Figures 1.12A and C). Curvilinear probes are arranged along a convex face and are typically of lower frequency than the linear probes. A phased-array (sector) probe generates an image from an electronically steered beam in a close array, generating an image that comes from a point and is good for getting between ribs, such as in cardiac ultrasound (Figures 1.12A and B). Both curvilinear and phased-array probes generate sector or pie-shaped images, narrow in the near field.
and wide in the far field (Figures 1.12A and D). Phased-array probes are typically lower frequency. Because of their smaller footprint, pie-shaped image, and common frequencies, the curvilinear probes are generally the most versatile and ideal for the focused, COAST³, and FAST³ studies.

Probes are generally named for the primary frequency they emit. For example, a General Electric (GE) 8C probe indicates that 8 MHz is its primary frequency and the C represents the probe’s curvilinear footprint. Moreover, a GE 9L probe indicates a 9 MHz primary frequency in a linear (L) probe, and a GE 7S as having 7 MHz as its primary frequency in a sector (S) probe. However, modern probes are capable of emitting a range of frequencies known as bandwidth. In choosing the best frequency, we need to go back to the basics. Remember that higher frequencies are attenuated more, and that means less penetration but better detail. Lower frequencies are attenuated less, and that means deeper penetration but less detail.

Gain

Gain is the overall brightness of the image. The ideal is not too bright and not too dark. The gain knob is the one knob that will adjust the overall setting. After first setting the overall gain, minimize dark or light bands across the screen by using the time gain compensation (TGC) knobs. These are usually sliders that adjust brightness along discrete bands across the image. The goal is to have a consistent brightness from top to bottom of the screen.

Frequency

Find a happy medium between penetration and resolution. Use the highest frequency (MHz) you can get away with and still see as deeply as needed.

Focal Position and Number

The US beam has a focus position where the beams narrow to give a more detailed image at a certain depth. The beams do not converge, as we may think of light focusing on the retina, because they will again diverge beyond the focal position. The physics of this can be found in additional references (Nyaland 2002). Both the focus position and number of focal points can be set by the sonographer. However, the processor can only handle a certain amount of information and by asking it to do more, it will reduce other items, normally the frame rate, or how many times/second the image is refreshed. High frame rates make for a smooth image, but take a lot of processing power. Low frame rates give a choppy image. Ask the processor to do more and it will respond by giving you a lower frame rate.

Presets, Abdominal, Cardiac, Small Parts, etc.

Even with just these four settings, that’s still a lot of knobs to be adjusting in the emergent situation. Modern US machines have a collection of imaging presets which the user may select based upon the area of interest (such as cardiac vs. abdomen vs. small parts and others) and patient size (adult vs. pediatric). It is prudent to remember, however, to adjust your depth.
Alternate Imaging Tools
Up until now, we have been talking about B-mode, or standard 2-dimensional, ultrasonography. A-mode has no practical bearing on the emergency scans outlined in this book and therefore will not be discussed. However, M-mode and color Doppler imaging are used in some focused, COAST3, and FAST3 protocols (see chapters 8 and 11).

**M-mode**
The “M” in M-mode stands for motion. This mode has also been called the “ice pick” mode because it reflects a small column of US waves but follows it over time. Cardiac US is where M-mode is best known. It can be a little challenging to understand what is being displayed on the screen, but using the B-mode view to show just where that “ice pick” is cutting through is helpful. M-Mode is used not only for certain cardiac studies, but also in certain lung studies and fetal imaging (see chapters 8, 10, and 11).

**Color Flow Doppler**
Color flow Doppler is used in combination with B-mode ultrasonography. It allows you to see flow of blood within a vessel and helps to determine the direction of that flow. Doppler is best when the flow is parallel with the sound beam. Color signatures are usually set up so that flow toward the probe is red and flow away from the probe is blue, although this can be set on most machines to user preference. Color flow Doppler has its limitations with low velocities.

On The Horizon

**Single Crystal Probes**
Single crystal probes emit a large bandwidth of sound beams instead of just one, thereby combining the benefits of high-frequency resolution and low-frequency penetration. The learning curve for imaging is generally much different than that of traditional multicrystal US probes.

**Smartphone Applications**
At the time of this writing, there is at least one smartphone-powered US device approved by the U.S. Food and Drug Administration (FDA). Technology is advancing quickly and one must wonder what the future holds for US imaging.

Recording Ultrasonographic Findings, Labeling Still Images

**Documentation of the Focused, COAST3 and FAST3 Ultrasound Exam**
Save the images. A medical record is not complete with just a written description of an image, whether that is a radiograph, an ultrasound image, a computerized tomography (CT), or magnetic resonance imaging (MRI). The image must be there to back it up. Furthermore, the other modalities have information to know exactly where an image was obtained. For the radiograph there are anatomic landmarks; for both CT and MRI, there is a pilot image that records where all the remaining images are obtained. For US images there may not be any definitive markers.

An US image that makes sense to the sonographer when it was recorded may make no sense when under review two days or even two hours later. One of the most common mistake veterinarians make is not labeling their images. Label the organ or structure of interest and label your orientation (longitudinal vs. transverse) if it is not evident from the image. There will be times when there are no anatomic landmarks evident on the image.

Most US machines have some sort of body pattern that can be placed on the image with an icon to show the approximate location of the probe (Figure 1.4A). Put all labels outside the image, too. Placing words across the image can potentially hide diagnostic information. If you must write across the US image, first save a picture of the unadulterated image and then save a second picture of the annotated image. Short video clips can also be saved on most US machines.

For recording US findings in medical records, see Appendix II with suggested goal-driven templates.